Quantifying ecological thresholds and resilience in stream ecosystems

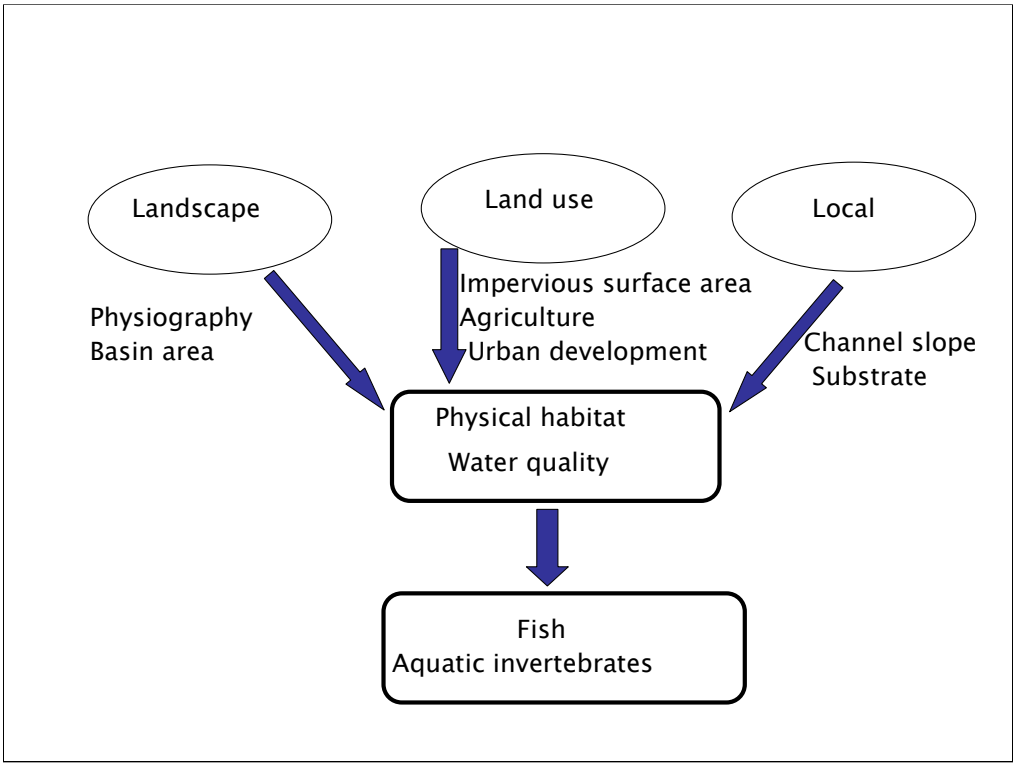
Robert H. Hilderbrand[1], Richard L. Raesly[2], Erik N. Powers[1], & Ryan M. Utz[1]

1Univ of MD Center for Environmental Science Appalachian Lab
2Frostburg State University

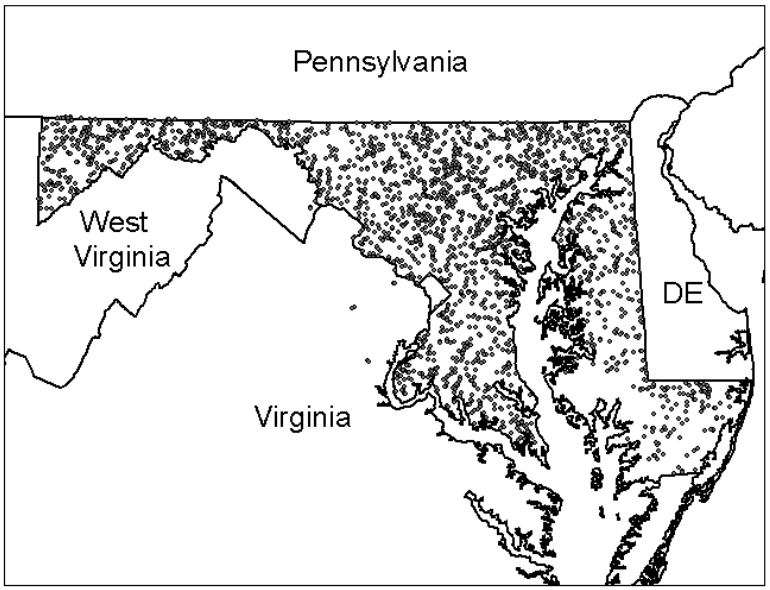
Ecological Significance

- Shifts from desired to undesired, degraded state
  - Fish – loss of biodiversity, recreation opportunities
  - Benthic invertebrates – loss of lower trophic levels, biodiversity, food for fish
- Surrogate for condition of watershed
- Implications for human health
  - Drinking water
  - Safety – flooding, contaminants

The study sites are stream ecosystems in the Mid-Atlantic area.

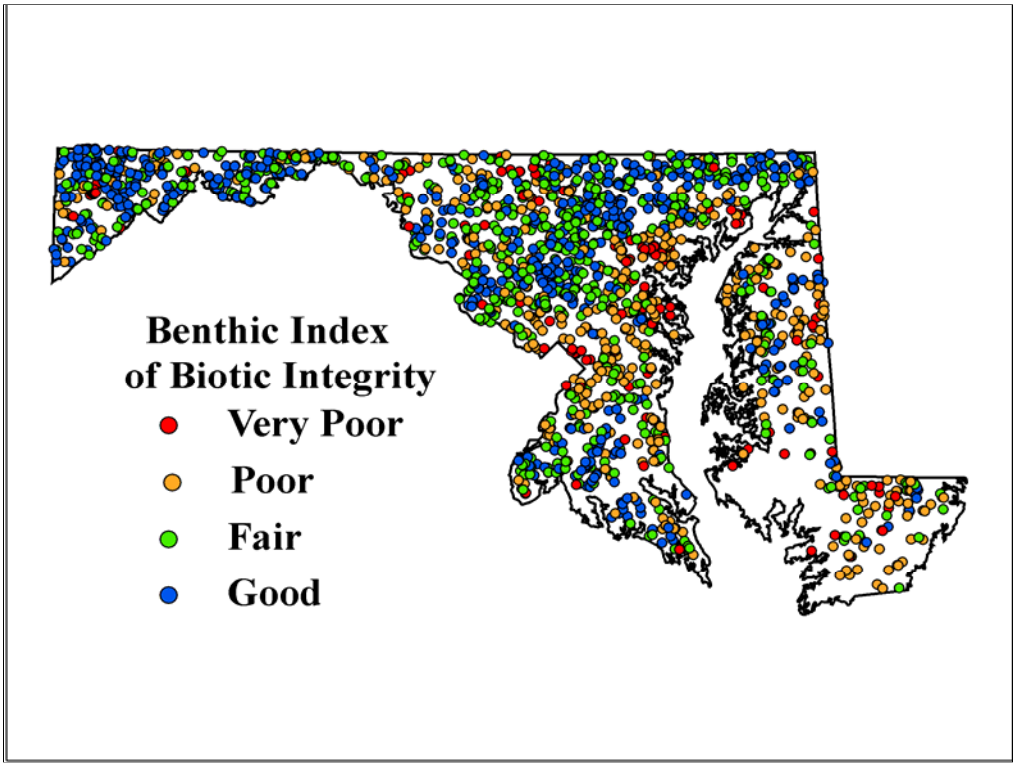

Landscape
Land use
Local
Physiography
Basin area
Impervious surface area
Agriculture
Urban development
Channel slope
Substrate
Physical habitat
Water quality
Fish
Aquatic invertebrates

Study Location – dots represent MBSS samples



The dots represent more than 2,000 sampling points. Samples are collected by the Maryland Biological Stream Survey, which is part of the Maryland Department of Natural Resources (DNR). Data include water chemistry in both the spring and the summer, physical habitat in the stream, benthic macroinvertebrate sampling, and quantitative fish sampling. Data have been collected since 1995.

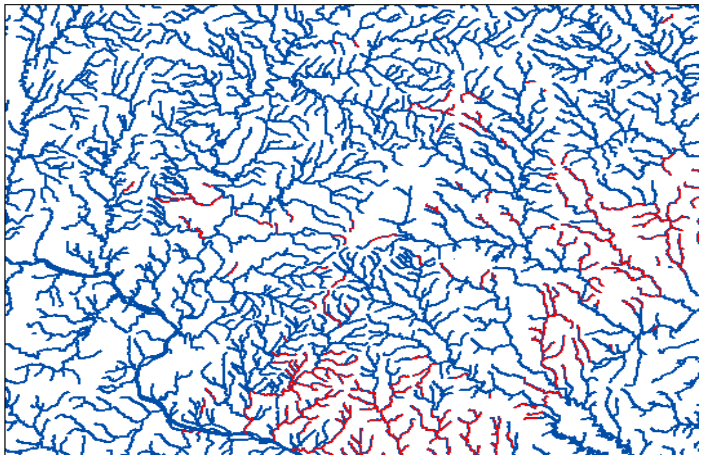
A stream can appear healthy but still be degraded.



In Maryland, there are three biogeographic areas: the Coastal Plain, the Piedmont Province, and the Highlands.

Ultimate Goals:

- Classify and predict stream vulnerability & resilience
- Futures scenarios of landscape changes

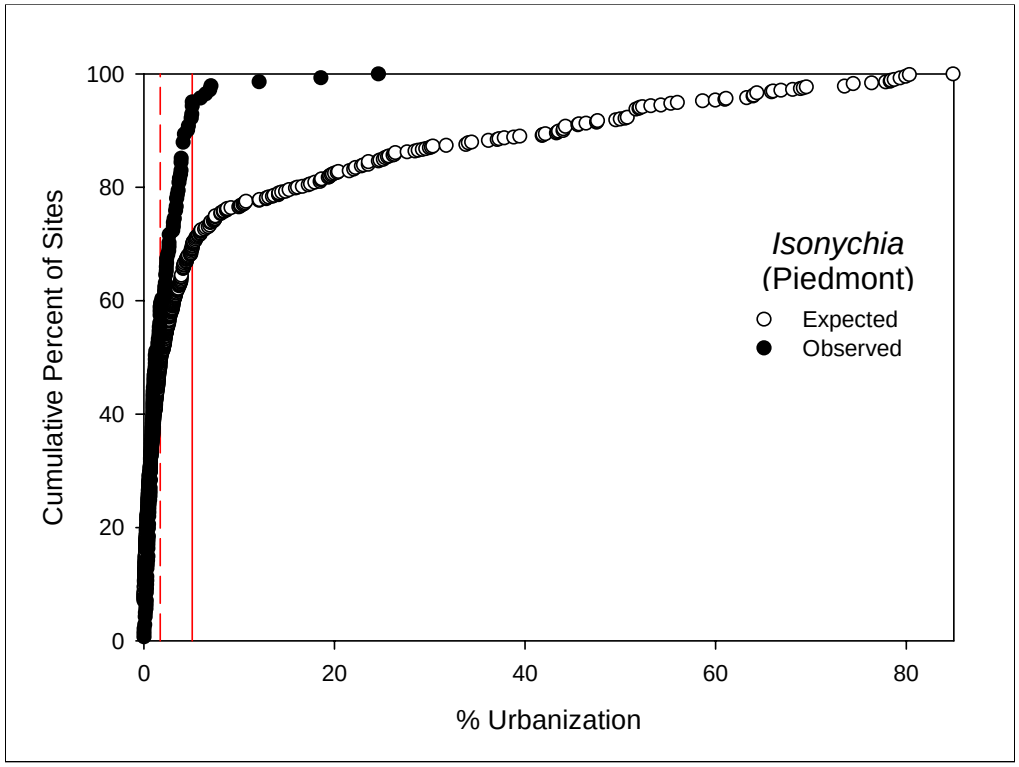


Approaches

- Individual taxa
- Assemblage/community
  - Structure
  - Functional groups – not yet initiated
  - Analyses carried out for each individual combination of stream order and physiographic region

Taxon specific approach

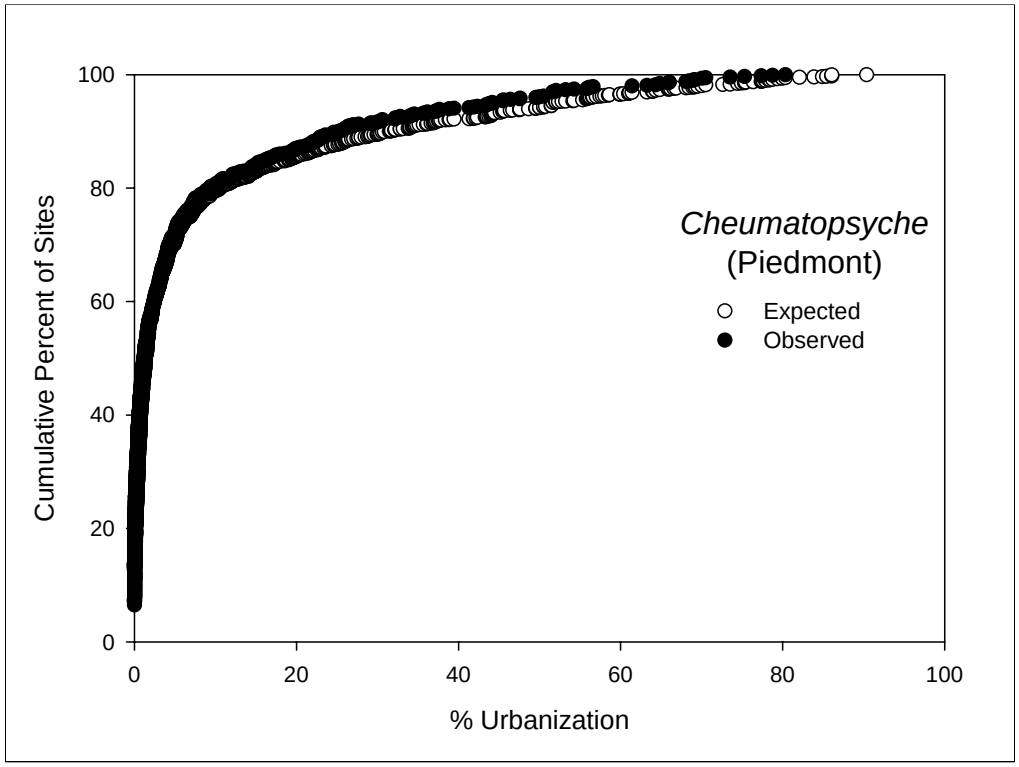
- Evaluate a wide range of taxa for responses to various stressors
- Compare distributions of observed vs. expected
- Creating a catalog of stressor responses to develop indicators (+ & -) of degradation for various stream types



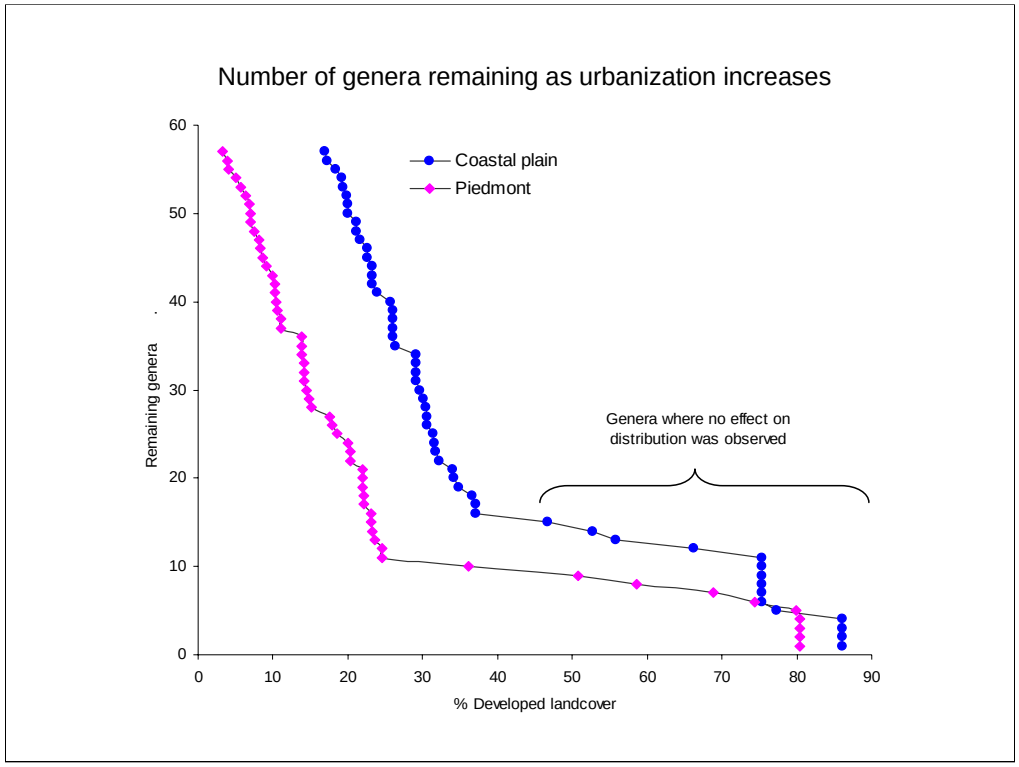
The *Isonychia* respond rapidly to changes in urbanization across the watershed.

An approach that is invariant to sample size was developed to study these species. Biogeographic and water chemistry differences were filtered out and the cumulative frequency distribution of all sites where the genus could potentially live was determined. This was compared to the actual distribution of the taxon. The cumulative frequency distribution at the 90th percentile was compared to the distribution of urbanization at the 90th percentile. If a significant difference in proportions was found, further analysis was performed. Either a change point analysis was performed or the area where the observed and expected values began to depart was examined. Where the two depart is not a threshold, but it is where degradation begins to occur for that taxon. Further analyses can be performed to determine the approximate threshold.

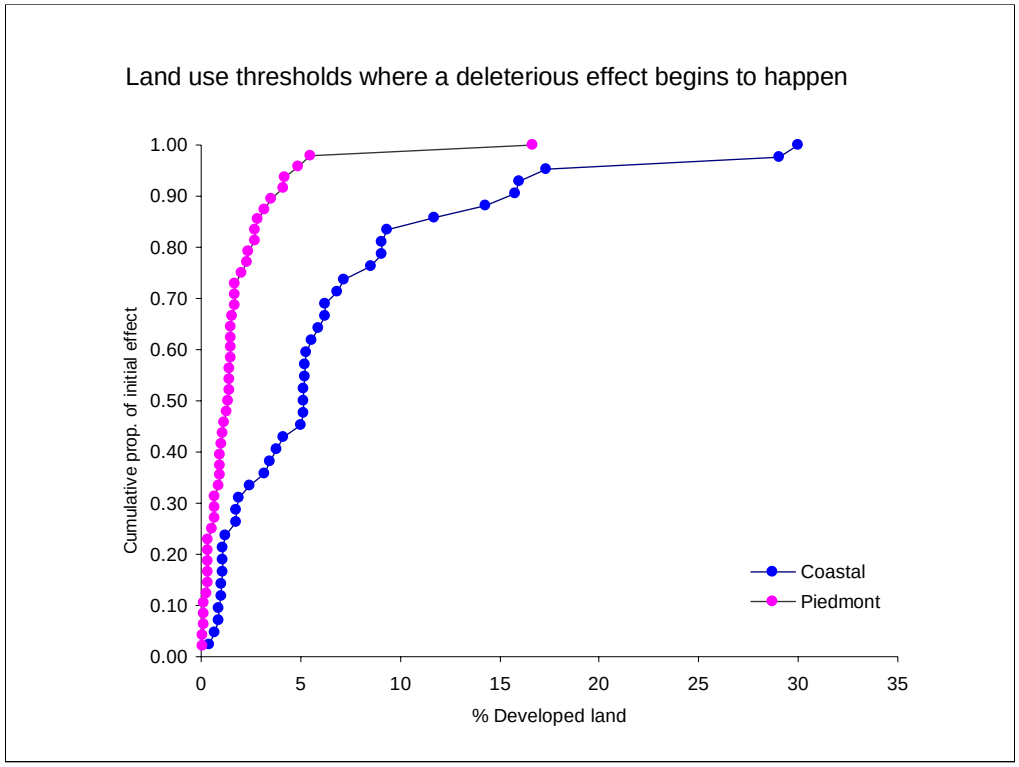
The solid vertical line represents the 95th percentile for the distribution of *Isonychia*. That is the upper limit threshold.



The *Cheumatopsyche* do not appear to change across the urban gradient.



Analysis was performed for several hundred invertebrate taxa across the two physiographic provinces, the Coastal Plain and the Piedmont Province. It appears that the taxa in the Piedmont streams are more vulnerable to developed land cover than the taxa in the Coastal Plain streams.



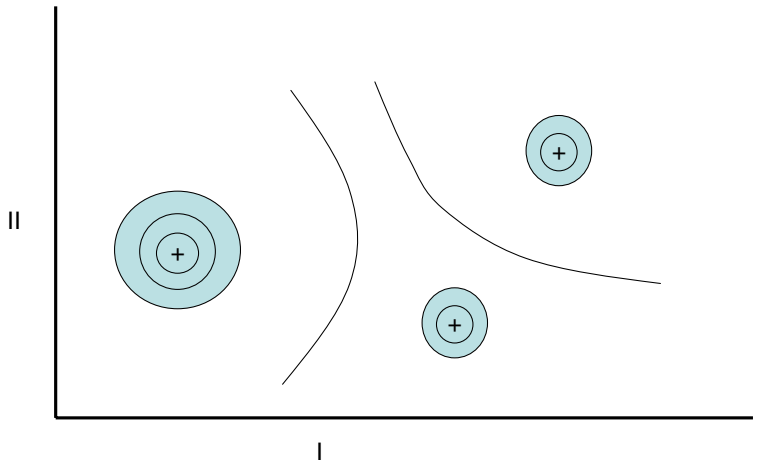
Even with less than 5 percent of the land developed, a large proportion of the Piedmont taxa has been affected negatively. Coastal Plains taxa are affected, but not as dramatically. Coastal streams appear to be more resilient than Piedmont streams.

Approaches

- Individual taxa

- Assemblage/community
  - Structure
  - Functional groups – not yet initiated
  - Analyses carried out for each individual combination of stream order and physiographic region

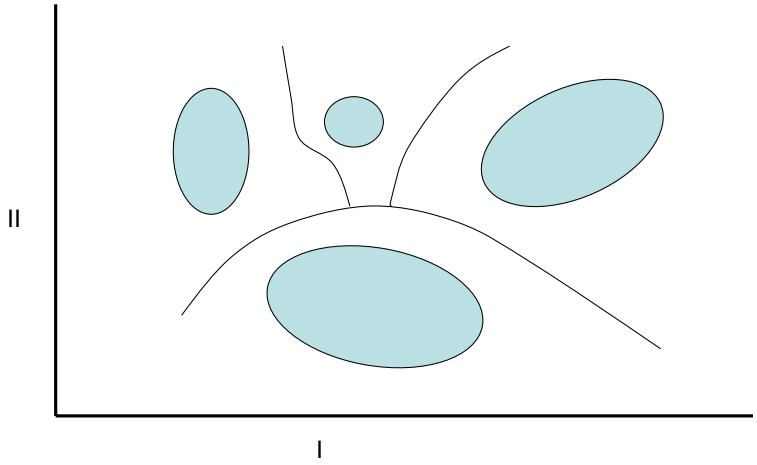
Sewall Wright and the Adaptive Landscape



The adaptive landscape model posits that certain combinations of genes are adaptive and confer high fitness to individuals.

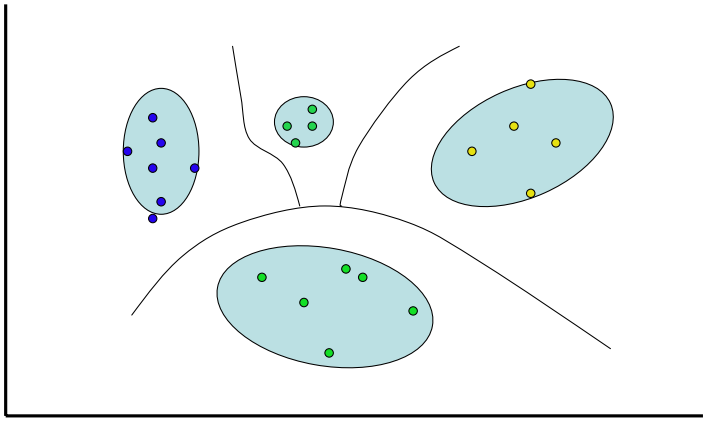
The Ecosystem Landscape

- The habitat template



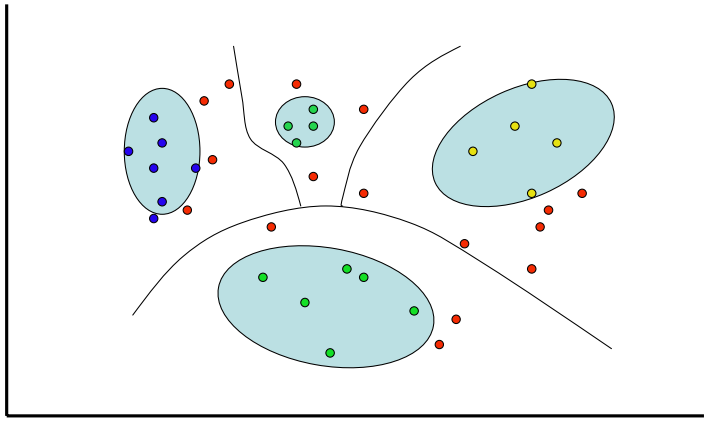
The Ecosystem Landscape

- The reference states of intact communities



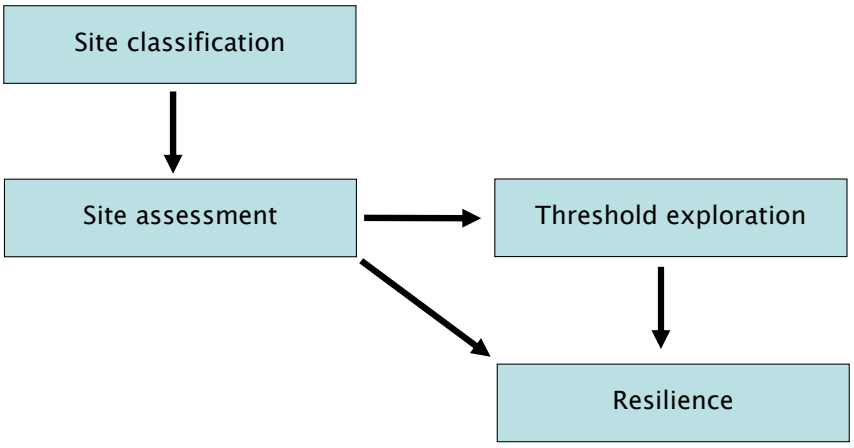
The Ecosystem Landscape

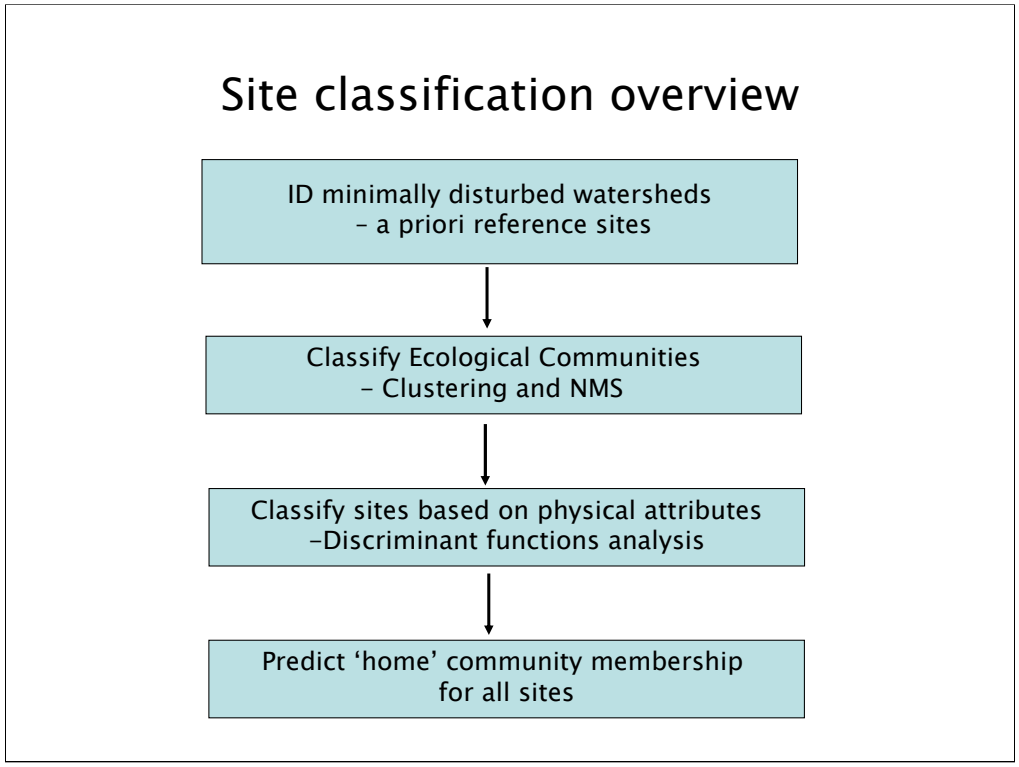
- The position of non-reference sites



Anything outside the prespecified domains is considered to be in a degraded state.

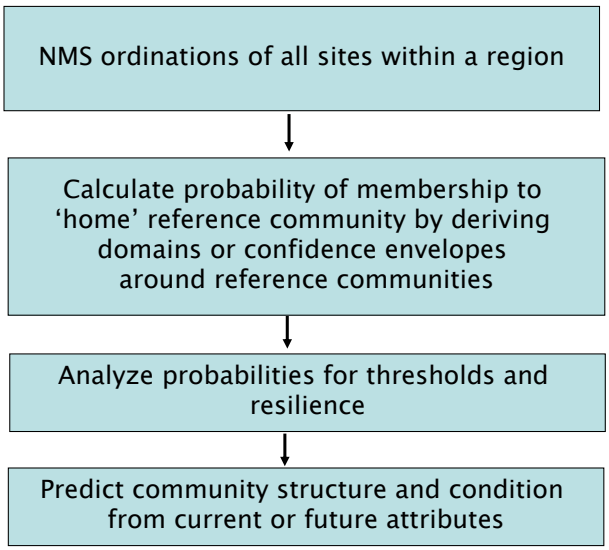
Analysis overview



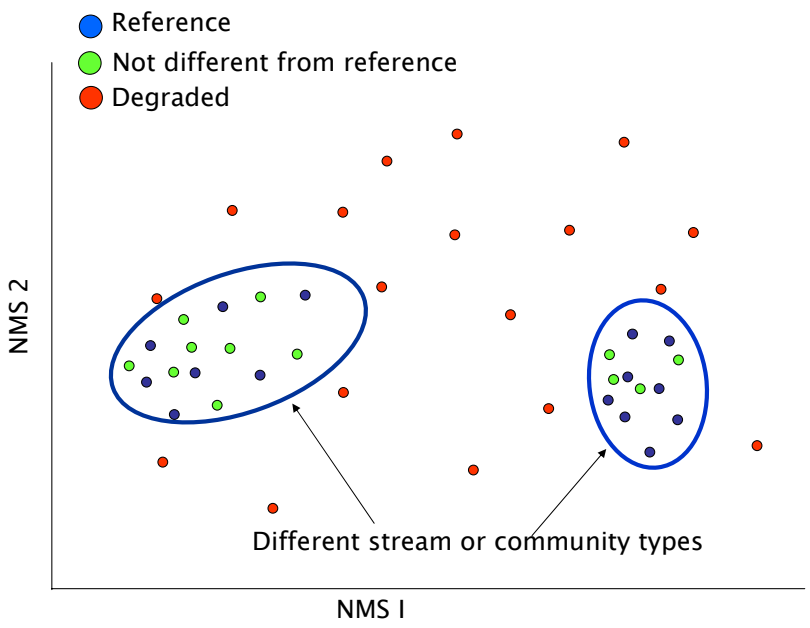


Minimally disturbed watersheds in the Highlands region are those with less than 1 percent urbanization, less than 2 percent agriculture, predominant forrestation, and very low anthropogenic disturbance. Landscapes in the Piedmont and Coastal Plains regions have been modified for the past 400 years, so they cannot be used as reference sites. Clustering analysis is performed to determine if there are any cohesive and distinctive communities. Sites are classified according to physical attributes. The data then are used to predict what a community might look like under minimally disturbed conditions.

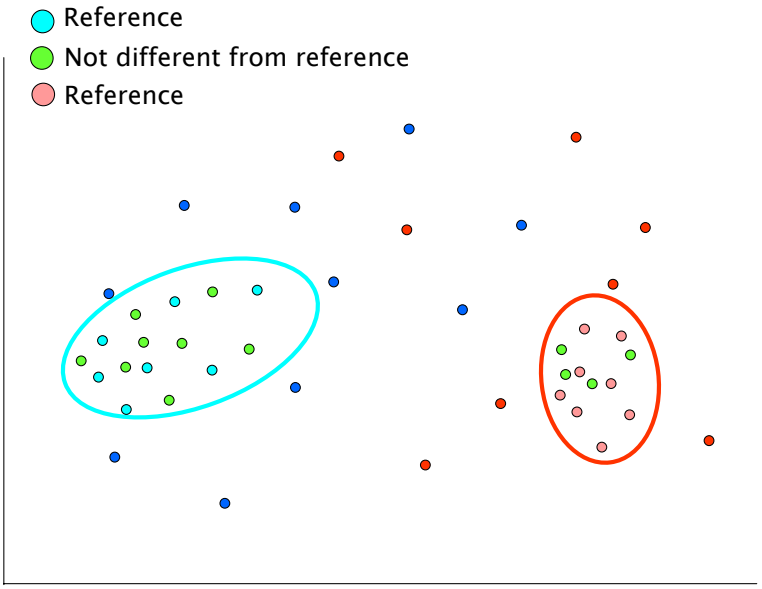
Site assessment overview

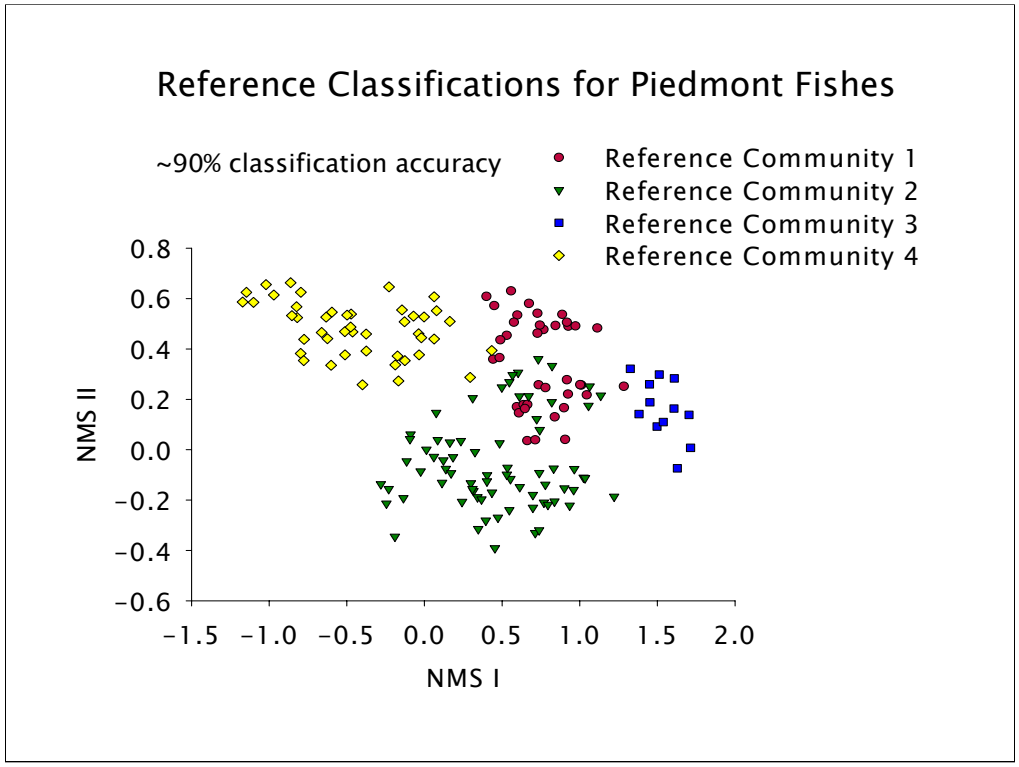


Underlying approach

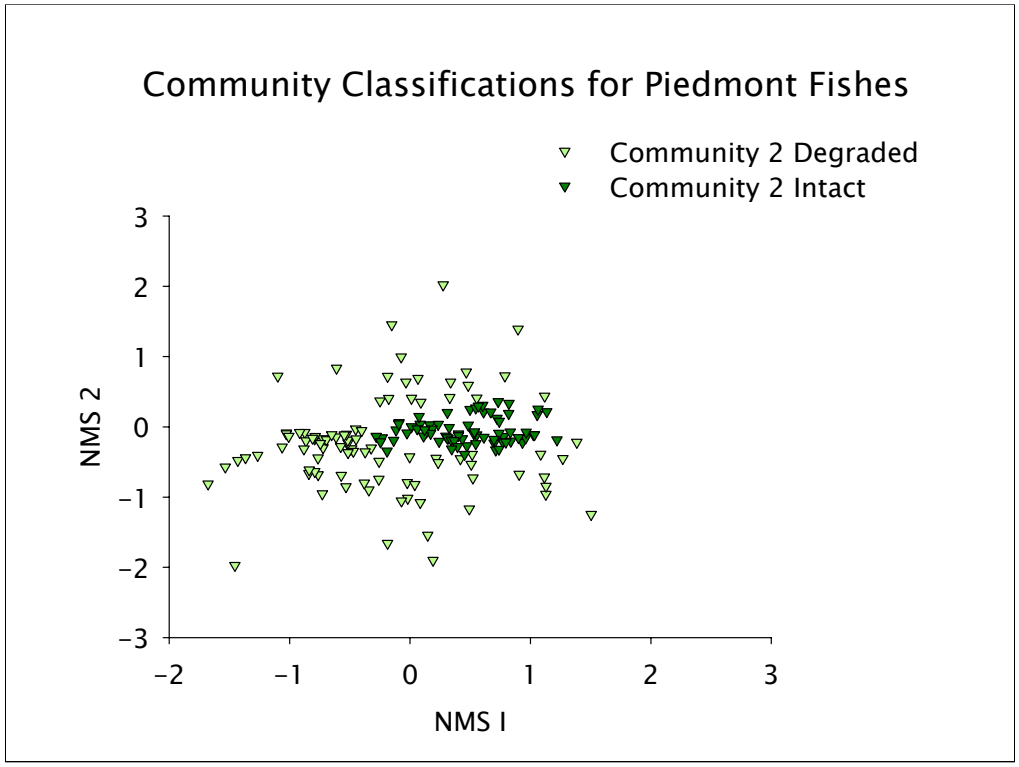


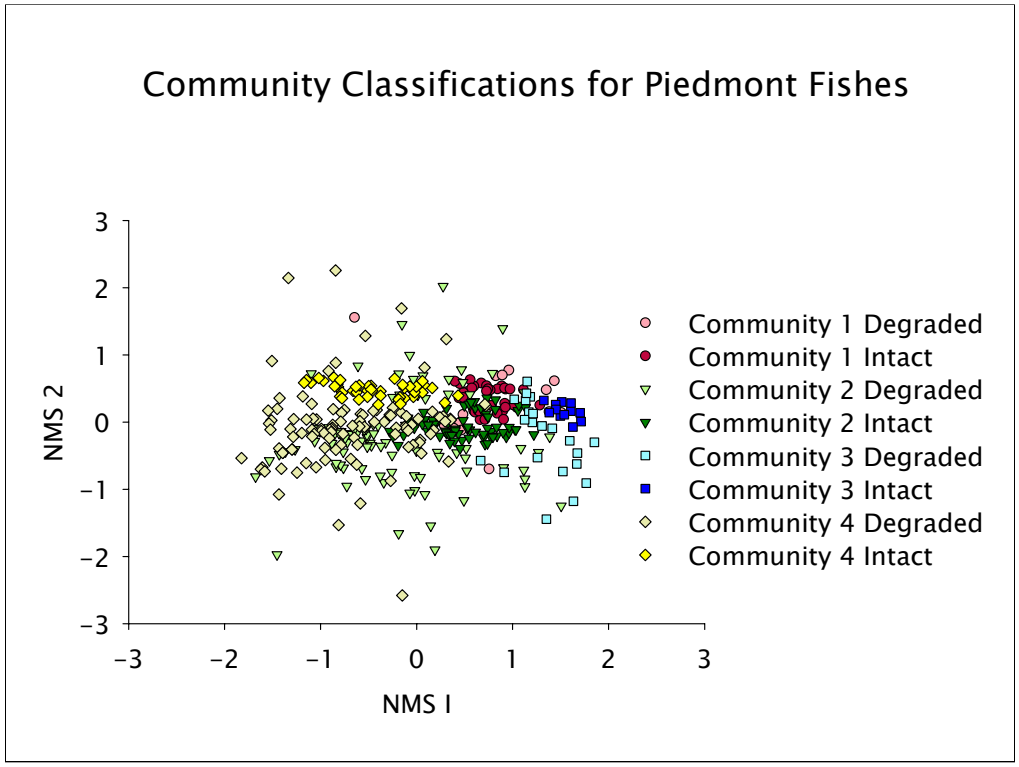
Underlying approach



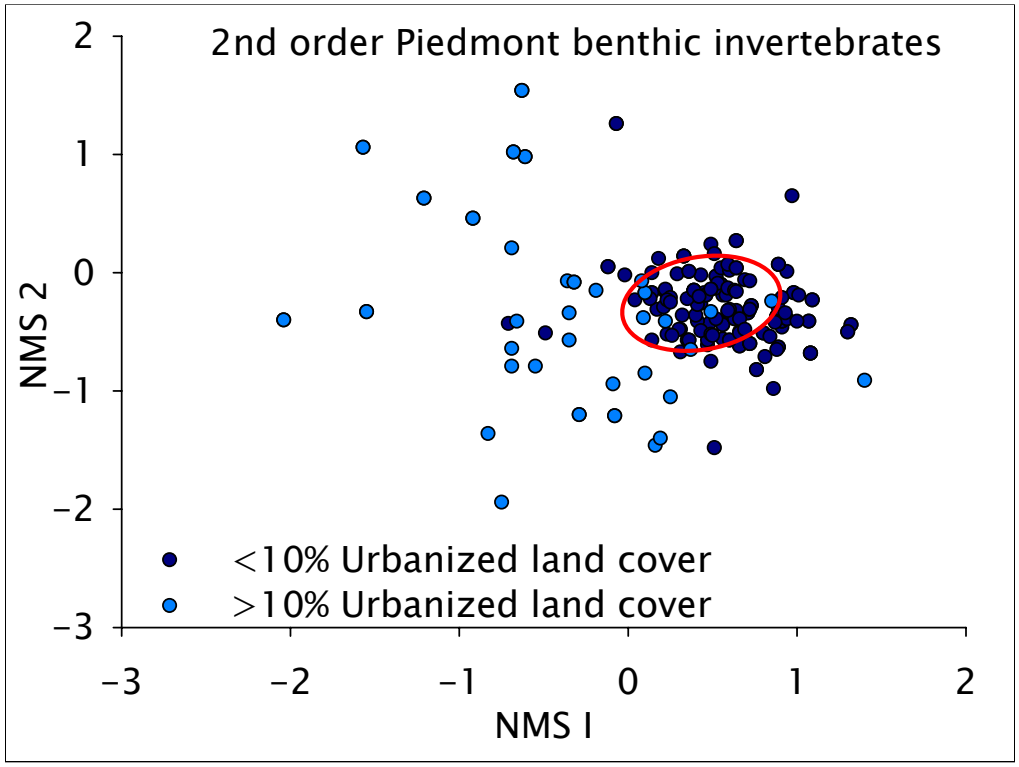


The communities appear to be very cohesive.

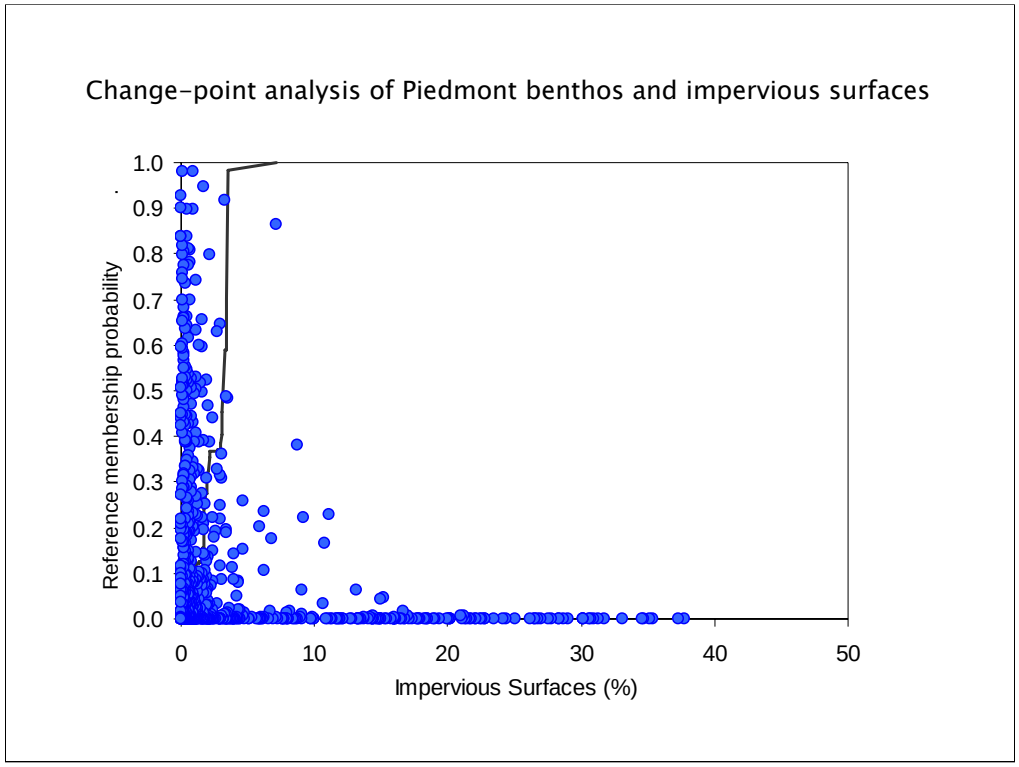

Community Classifications for Piedmont Fishes
Community 2 Degraded
Community 2 Intact
NMS 2
NMS I
3
2
1
0
−1
−2
−3
−2
−1
0
1
2
3



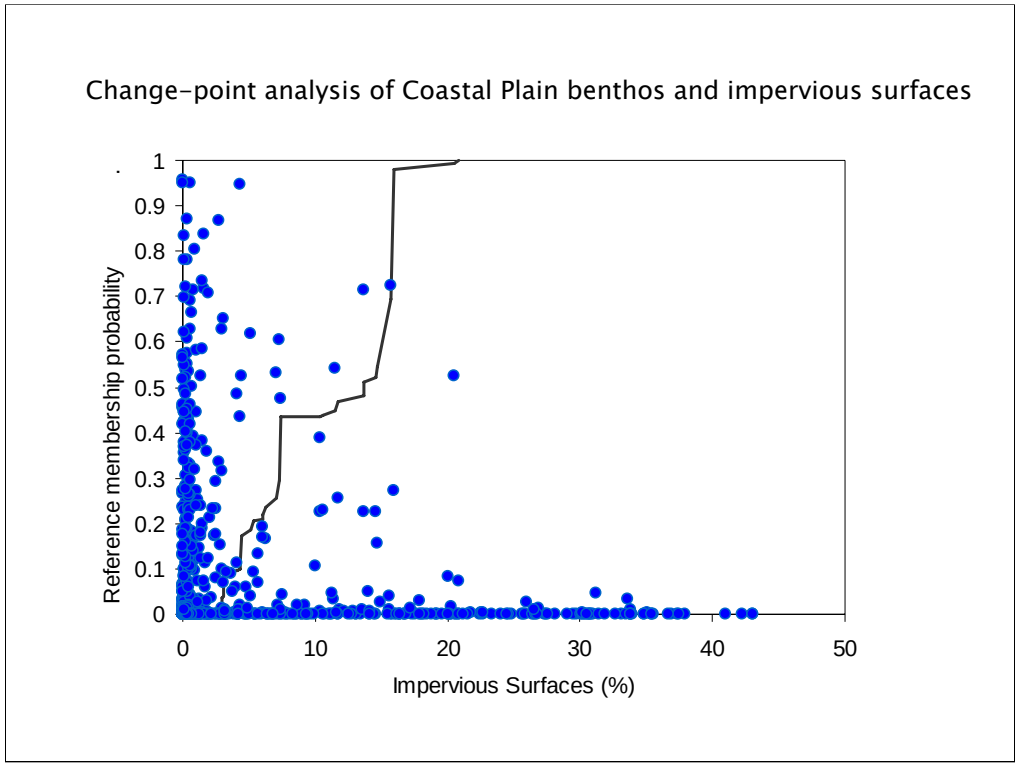
The degraded sites are clustered together, which may indicate a domain of degradation. Land use or structural features may be forcing the communities into these domains.



If an area is highly urbanized, it is not likely to be in the reference domain.

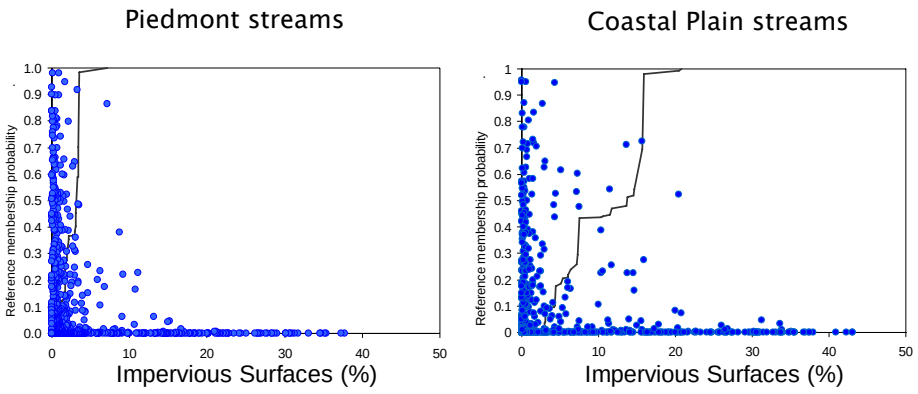


There is a strong relationship and point of departure at approximately 5 to 6 percent.



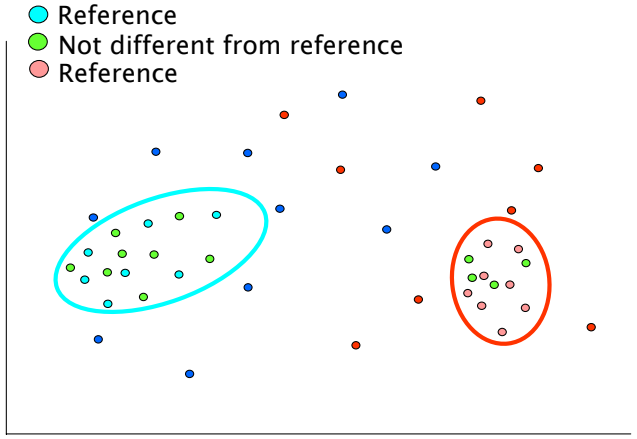
Change points appear at about 15 percent impervious surfaces.

Comparing Piedmont and Coastal Plain stream community responses

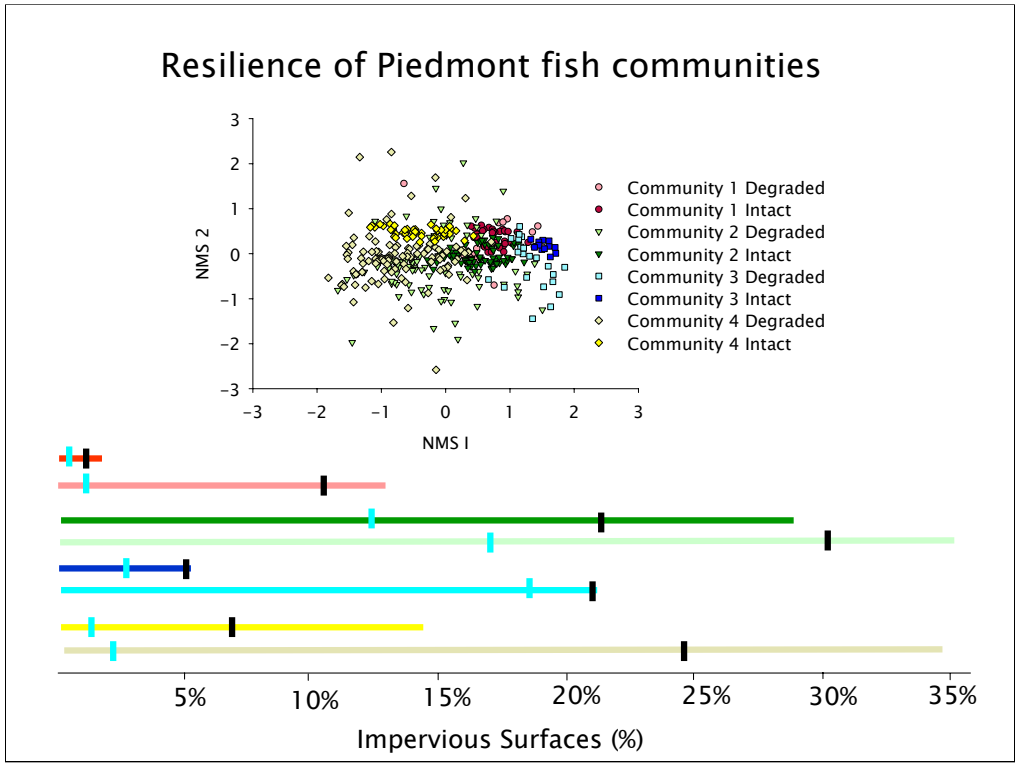


The Piedmont streams have a much lower threshold for responding negatively to impervious surfaces, whereas Coastal Plains streams appear to be more resilient.

Resilience

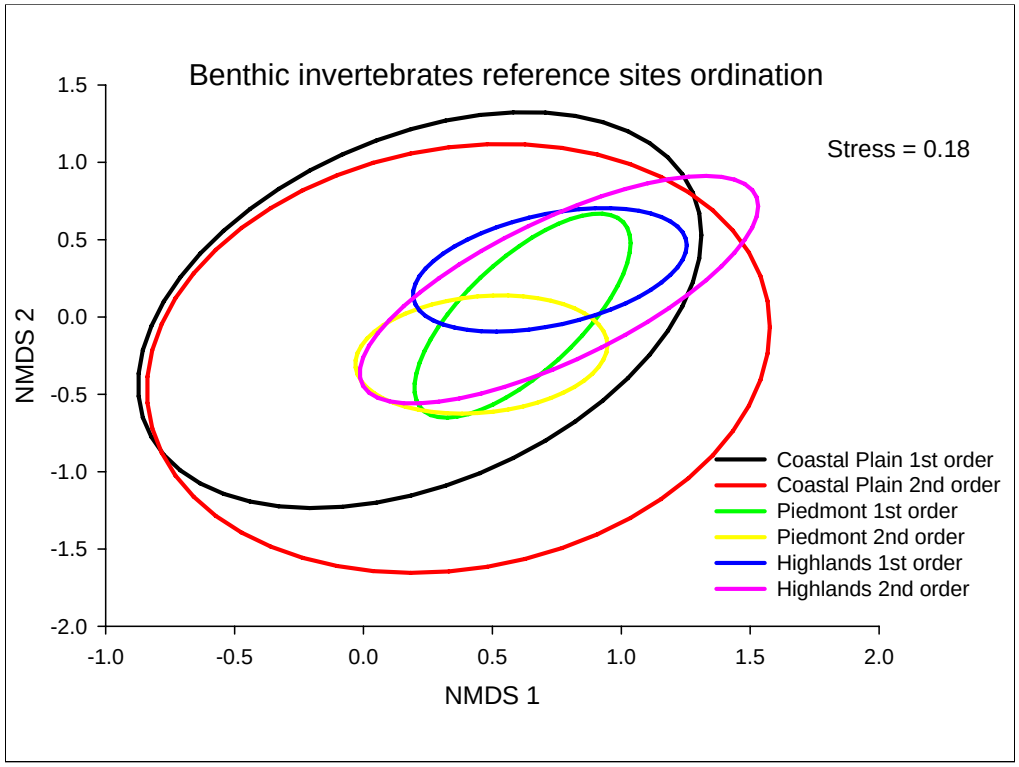


Measure width of reference domains for a particular stressor

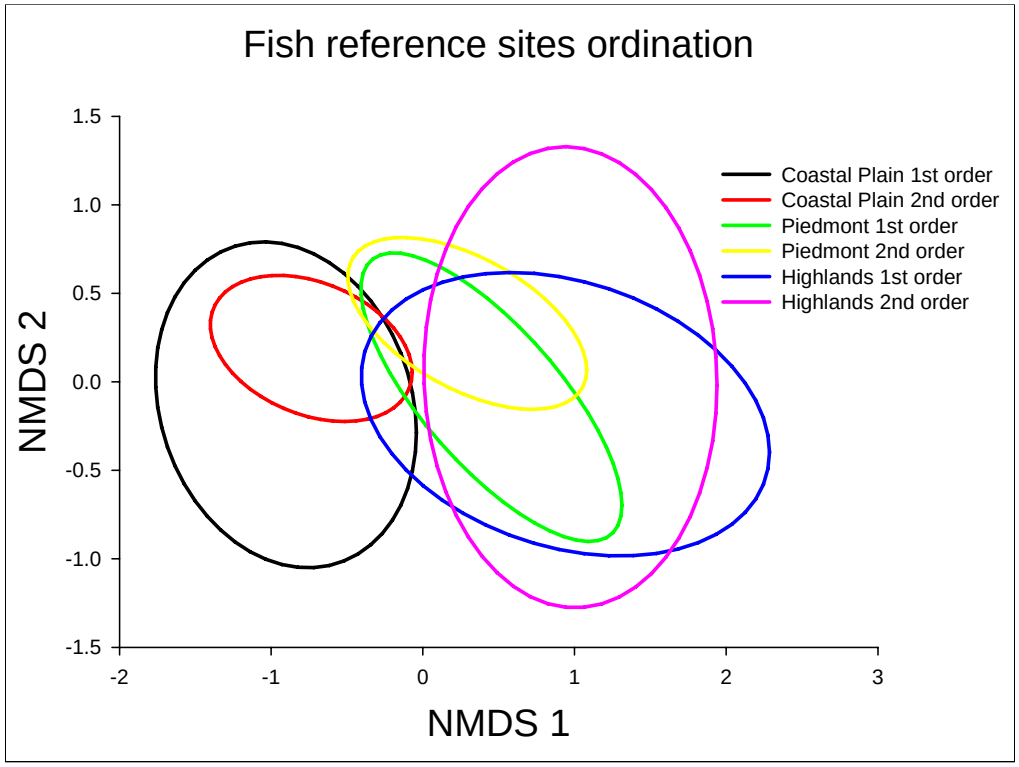


The intact streams in the red community are clustered in one area, and the degraded streams in this community span a very wide range. It appears that the red community has low resilience and high vulnerability to impervious surfaces. In contrast, the green community appears to be very resilient to impervious surfaces. The blue community appears to be very vulnerable to impervious surfaces. The yellow community appears to be somewhere in between.

This graph shows the importance of studying streams at a more detailed level. Studying streams on a larger scale may introduce other variables that can alter the true picture.



The black and red lines represent the benthic invertebrate communities in the Coastal Plain. In contrast, the Piedmont and Highlands streams have much more narrow domains with considerable overlap.



From a fish perspective, there is much more biogeographic separation.

Thresholds & Resilience

- Thresholds appear to exist
  - Not catastrophic, but apparent
  - Matter of scale – spatial range of evaluation important
- Evidence of differential resilience
  - Geographic
  - Channel types / communities

Impervious surfaces most likely do not cause degradation directly. Instead, impervious surfaces are a surrogate for a wide range of other variables, such as altered hydrologic regime, increased stream temperature, enhanced erosion, habitat degradation, and so on.

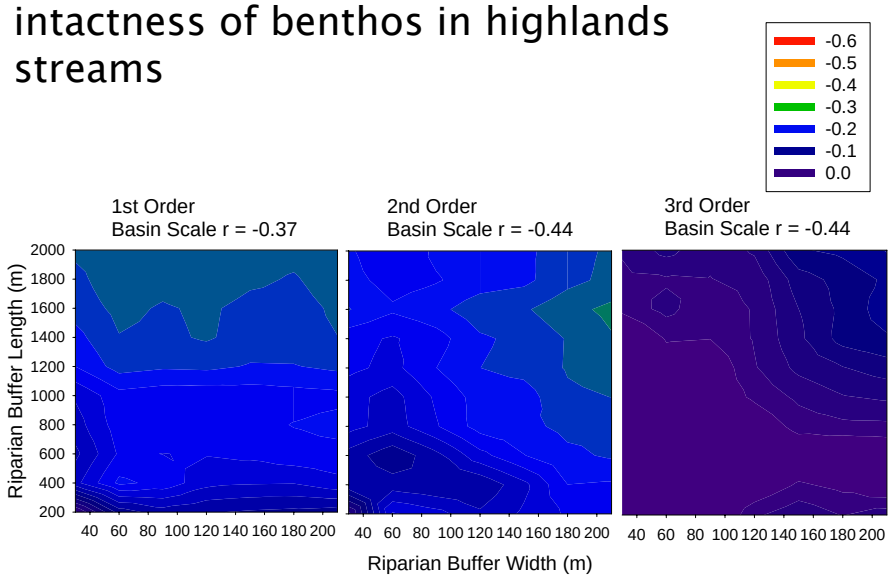
Alternate states

- Continuum or abrupt and discrete groups?
  - Probably both and dependent on stressor
- Reversibility of regime shifts?
  - Most shifts seem to be due to semi-permanent landscape changes, so reversibility is unknown

Spatial influences of land use

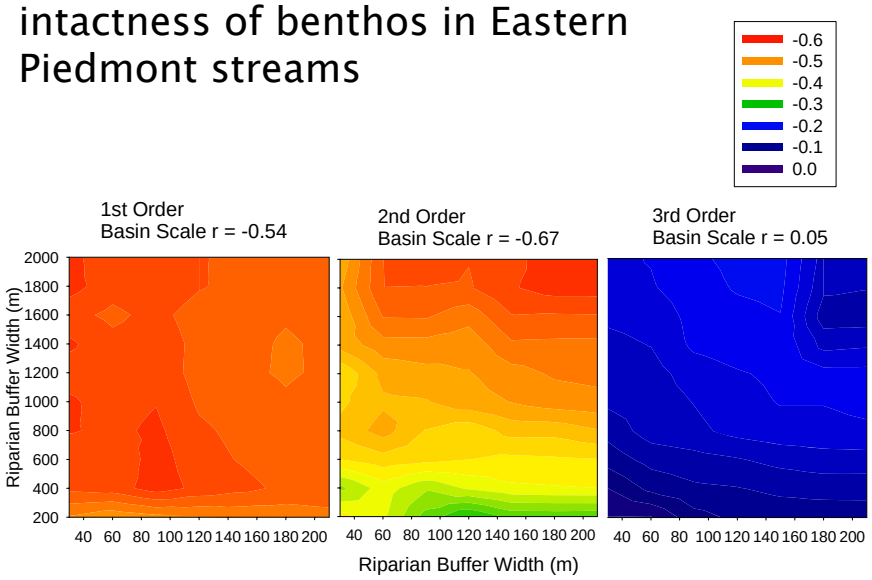
- Examining proximity and magnitude of land uses near streams
- At what scales should we be interested?
- Influences of land uses within various combinations of riparian buffer widths and lengths near sampling sites

Correlations between impervious surfaces in riparian buffers and community intactness of benthos in highlands streams



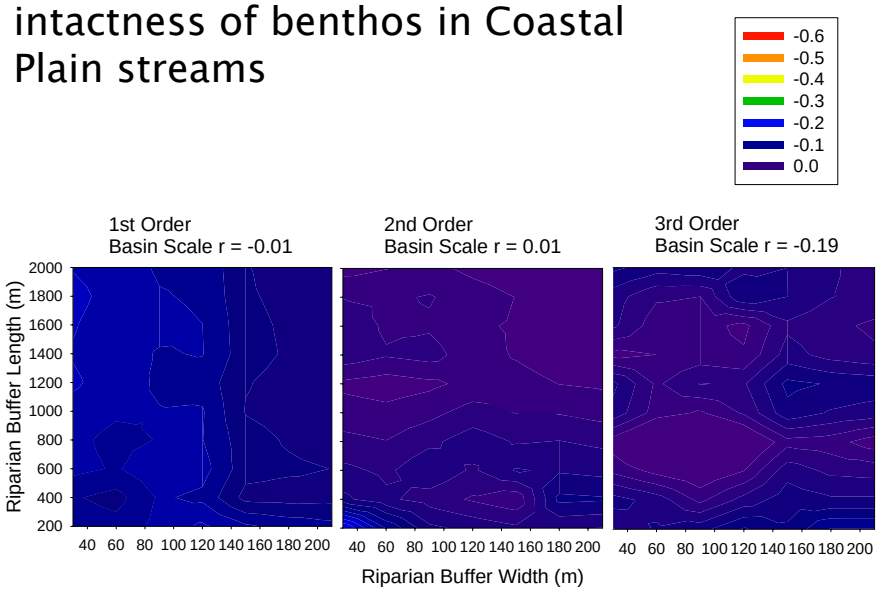
Highland streams do not appear to respond to impervious surfaces.

Correlations between impervious surfaces in riparian buffers and community intactness of benthos in Eastern Piedmont streams



Riparian buffers alone are not enough to repair a watershed.

Correlations between impervious surfaces in riparian buffers and community intactness of benthos in Coastal Plain streams



Coastal Plains streams do not appear to respond to impervious surfaces.

Surprises or lessons learned

- Differential resilience in differing regions
- Thresholds are a matter of scale
  - Little evidence for catastrophic thresholds
  - Region specific
- Good ability to classify sites into their respective reference communities from physical data
  - potential for identifying restoration endpoints from landscape data

Uses for findings

- Defining what a ‘restored’ community should look like given physical attributes of streams
- Land use planning to avoid degradation or state shifts
- Futures scenarios

Inquiries – interest in research

- MD DNR
- National Park Service
  - Using some methodologies for broader condition assessments of national parks
- MD Department of Planning

For more information

The ASTERS Project

Alternate States, Thresholds, & Ecosystem Resilience in Streams

- http://www.al.umces.edu/~bhilderbrand/research/asters%20project/asters%20home.html

A participant asked how Dr. Hilderbrand and his colleagues accounted for introduced species. Dr. Hilderbrand responded that they considered introduced species to be part of the community. Introduced species do add to the variation at a site, which makes their approach a little more conservative. The participant wondered if the analysis could be done with just the native species to determine what is driving the changes. Dr. Hilderbrand stated that this was an excellent idea and something that he and his colleagues may pursue in the future.

One participant stated that the graph on the Change-Point Analysis of Piedmont Benthos and Impervious slide showed considerable variation. The variation indicates that there are other variables (besides impervious surfaces) affecting the watersheds. The participant asked if Dr. Hilderbrand thought that incorporating some of those other variables would result in a clearer threshold. Dr. Hilderbrand pointed out that the models shown were single-variable models that do not represent the study endpoint. He and his colleagues plan to develop aggregate models to better predict thresholds.